

THE WORLD OF CHEMISTRY

Program #3

MEASUREMENT:  
THE FOUNDATION OF CHEMISTRY

Producer Doug Bolin

Air Script: October 31, 1988

PRODUCED BY  
EDUCATIONAL FILM CENTER  
and  
THE UNIVERSITY OF MARYLAND

## THE WORLD OF CHEMISTRY

Program #3: Measurement:  
The Foundation of Chemistry  
Producer Doug Bolin  
Air Script: October 31, 1988

Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Sunrise,  
underwater shots,  
pollution, drinking  
fountain, chemists at  
work in the lab

NARRATOR (MUSIC under):  
A bay at sunrise. Beneath the beauty, a  
natural process is affecting marine life.  
How much change can the fish take? A  
river, bubbling with pollution and  
controversy. How much of what is  
harmful to health. A drinking fountain.  
Healthy teeth depend on the fluoride  
added. But what is the right amount.  
The answers depend on chemical  
measurement. It is not enough merely to  
ask what is there, it is essential to  
determine how much. And to be sure  
the measurements are accurate.  
Measurement is truly the foundation of  
chemistry.

SUPER: MEASUREMENT,  
THE FOUNDATION OF

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in lab

ROALD HOFFMANN (SYNC):

Welcome to the laboratory. Look at all the stuff around -- glassware, instruments, bottles of chemicals. An experiment is going to begin. But before we begin, we have to measure. In order to help us measure, to help our senses, what we have done is to invent a number of devices and instruments. Here is one of them that you are familiar with. It's a thermometer. Some others are over here. This is a buret -- an ingenious device for delivering a very precise volume of a liquid. Here is a modern analytical balance. But you know, there is really nothing new about our concern with measurements. I recently went to a museum and saw some 5,000 year old clay tablets. And, do you know what was recorded on them? A dispute on weights and measures. Why is it that measurement has been so important to us throughout history? And in particular why is it that accurate and precise measurement is at the heart of modern chemistry?

MONTAGE: City scenes, gas,  
chemists working in labs,  
hospitals shots, graphic,  
miners, factory shots,  
people eating and  
drinking

NARRATOR (MUSIC and NAT  
SOUND under):

Try to imagine a part of your day that doesn't depend on measurement. Most of our activities could not occur without measurements, it forms the foundation of modern science and technology. In medicine, scenes like this are repeated countless times each day as researchers measure the chemicals in our bodies. Treatment and appropriate medication depend upon measurement. At the submicroscopic level, measurement of DNA's structure has helped to unlock our genetic code. And beneath our earth, measurements guide scientists as they draw samples and analyze them in the laboratory. In manufacturing, chemical measurements control the make up and strength of products. Measurement makes the steel for our cities stronger, then fits our cities together. The purity and composition of what we eat, what we drink, and what we breathe all depends on chemical measurement. Every day, we rely upon these measurements to guide us through our lives without giving them much thought. (cont.)

NARRATOR cont:

To the scientist, however, measurement is a constant search for the true value of what is being measured. How do chemists accomplish this goal? Series demonstrator Donald Showalter.

DS in lab

DON SHOWALTER (SYNC):

Chemists are always measuring things. Their goal is to get as close to the true value of the measured quantity as they possibly can. What is the true value of the mass of this antacid tablet? Let's weigh it on this balance. It weighs 1.1 grams on this balance. I have a second balance. It's a little bit more sensitive. By more sensitive I mean now that this balance weighed to the first decimal place; to the tenth of a gram. Where as this one now weighs to the third decimal place -- to the thousandths of a gram or a milligram. It weighs 1.137 grams. But is this the true value of the mass of this tablet? Now this is an analytical balance. It's one that chemists commonly use to measure small masses. Let's see what it weighs on here. This should be the most sensitive measurement. The one closest to the true value. It weighs 1.1362 grams. But I have a question for you. How do we know that this balance is giving us an accurate measure of the mass of this tablet? (cont.)

DON SHOWALTER cont:

Actually we can't be sure unless we've already done an important step. Now this object is called a standard mass. It might be tiny but it has a very important function. It weighs exactly 1 gram. Now if this balance shows us that, then we'll know it's working properly. As you can see it is. But I have two far more basic questions for you. How do we know if the mass of the standard is exactly one gram? And how do we know that what we are calling one gram is the same measurement that everyone else is calling one gram?

Shots at National Bureau of Standards (safe, kilogram, exterior, lab work)

NARRATOR (MUSIC and NAT SOUND under):

Part of the answer rests in this safe, protected by contact alarms and a special glass container. It sits in the sub-basement of a government agency near Washington, D.C. This is the standard kilogram, the mass standard for all of the United States. All measurements of mass that are done in this country start with the standard kilogram as a reference point. The National Bureau of Standards keeps the kilogram here at its national headquarters. The chief concern of scientists at the bureau is measurement. (cont.)

NARRATOR cont:

They are devoted to designing and testing new measurement systems, then refining them to increase their accuracy. They also maintain the standards for every other type of measurement that we do. Why are standards so important? Stanley Rasberry is director of the Standard Reference Materials Division.

INTERVIEW: Stanley  
Rasberry, Director of the  
Standard Reference Materials  
Division, National Bureau  
of Standards

SUPER: Stanley Rasberry

STANLEY RASBERRY (SYNC):

A standard in this case is an actual physical embodiment of weight or mass and it can be intercompared in different countries and in different places within the same country so that people always agree that this is a given mass. Most of analytical chemistry ties right into the kilogram because in analytical chemistry the job of the analytical chemist is to decide how much there is of specific elements or specific molecules in a mass of a product.

Super tankers, drawings of  
measuring the king's foot

NARRATOR (MUSIC under):

But long before chemists began using standards, they were being used to ease international trade and communication. Early standards weren't always practical. For example, the basic standard for measuring length used to be the king's foot.

INTERVIEW: Stanley  
Rasberry cont.

STANLEY RASBERRY (SYNC):

But of course the king in Germany would have a different length of foot than the king in France or the king in England or the king in Italy so this could lead to very serious trade problems -- communication problems. It doesn't really matter too much what you define a meter to be -- you could define it as a very small length like the length of your pen. But unless everyone in the world agrees that that's a meter then you don't have a standard of measurement that's adequate to today's world.



MONTAGE: Measuring  
devices

NARRATOR (MUSIC under):

Scientists also use standards to insure that their measuring devices are working properly. For testing balances, a weight that has been certified by the Bureau of Standards can be used. However, with more sophisticated measuring tools, a different type of standard is needed.

INTERVIEW: Stanley  
Raspberry cont.

STANLEY RASBERRY (SYNC):

A 90% or more of the practical work done in analytical chemistry is done with instruments and the instrumental analysis requires some kind of measurement standard to be run right on the measuring equipment -- you don't go to a balance at all -- you don't separate out elements at all to be weighed on the balance.

Measuring and making  
certified mixed diet,  
food shots

NARRATOR (MUSIC under):

This mixed diet is an example of a standard that can be run directly on a measuring instrument. To prepare it, scientists start by gathering what statistical studies say is a normal diet in different regions of the country. (cont.)

NARRATOR cont:

The food is cooked, then mixed together. The resulting mush is freeze dried. Next, the key elements are measured in several independent laboratories. When all the independent measurements agree the amounts are certified. The freeze dried diet can now be used as a standard.

INTERVIEW: Stanley  
Raspberry cont.

STANLEY RASBERRY (SYNC):

Taken with its certificate out to the nutrition lab, it becomes a very important quality insurance sample for nutrition chemists. They're trying to find out how much selenium is harmful, how much aluminum is harmful, or are those essential elements. Perhaps you need one part per billion of selenium but if you get a hundred parts per billion of selenium it becomes harmful. And as they make all those studies they need accurate analyses. This kind of material helps them to home in on that accurate analysis by being able to run this material and check and see if they get the certified value for the selenium or the arsenic or the chromium or the nickle, copper any of the other elements that are in this average human diet

RH next to river

ROALD HOFFMANN (SYNC):

We've just seen how important standards are in measurement. Cause unless we agree we can't be sure that the measurement is right. Here is a body of water. I think it might be polluted. You know if I wait for the fish to come up to the surface dead that's much too late, the environment might be gone at that moment. What I've got to do is to detect a possible pollutant at a part per billion level even. How do chemists come up with ways of measuring such small amounts?

MONTAGE: Sunrise, ocean,  
river, wildlife, measuring  
and sampling bay water,  
underwater shots, bay  
shots, fishing, chemists  
at work in lab

NARRATOR (MUSIC and NAT  
SOUND under):

A bay at sunrise. It has a unique beauty, yet Chesapeake Bay typifies human interaction with the oceans, streams and lakes of our planet. Because the Bay is so valuable to us, researchers are constantly at work studying its chemistry. They also monitor the effects of this chemistry on the plants and animals living in the Bay. (cont.)

NARRATOR cont:

Chesapeake Bay is an estuary, a huge mixing bowl for fresh and salt water. Each day, large amounts of fresh water from streams flows into salt water from the Atlantic Ocean. So parts of the Bay are more saline, more salty, than others. Marine life is affected, and so are the livelihoods of fishermen. For salt water fish can die if salinity is too low. So, government agencies constantly test the Bay's salinity levels to within a few tenths of a percent -- or within several parts per thousand. They do this by taking samples of water from the Bay at different sites and on different days -- in order to gain a picture of the Bay as a whole. But once the samples are taken, how is the level of the salinity determined in the laboratory?

DS in lab

DON SHOWALTER (SYNC):

Frequently in nature as well as in the laboratory we are dealing with substances that are in solution. It very well might be difficult to separate out the components and weigh them. What we can do is directly measure the concentration of the sample -- that is the amount of substances dissolved in a certain volume. The technique we will use is called titration. The first step is to prepare a standard solution -- in this case a solution of silver nitrate. (cont.)

DON SHOWALTER cont:

We would weigh accurately on this balance a certain amount of silver nitrate -- in this case 1.00 gram. We would introduce that silver nitrate into a flask like this. We will then add water to dissolve the silver nitrate and finally dilute up to a volume of 100 milliliters.

EQUATION

We now have one gram of silver nitrate dissolved in a hundred milliliters of solution.

EQUATION

That is 0.0100 grams of silver nitrate per milliliter of solution. We would introduce this solution into this device called a buret.

Close up of buret  
and solution

NARRATOR (NAT SOUND under):

The buret, a long slender tube with volume marks on the side will allow us to add the solution of silver nitrate drop by drop to this sample of Chesapeake Bay water. The Bay water must be stirred during the process to insure a complete mixing of the silver nitrate and the chloride.

DS in lab

DON SHOWALTER (SYNC):

When we add the standard solution of silver nitrate to this sample a chemical reaction will occur. I'm adding this substance so that we will be able to tell chemically when the reaction is complete. We need to add the standard solution very carefully in order to perform an accurate measurement. As we add the standard solution to the sample of Chesapeake Bay water it turns milky white at first. The silver nitrate in our standard solution is reacting with the chloride in our Bay water. The chloride is the substance that determines how saline the Bay water is. So we want to find out exactly how much of it is dissolved in this sample. Now see the pink color -- this means that all the chloride in the sample has reacted with the silver nitrate in the standard solution. We have used 22.5 milliliters of standard solution.

EQUATION

Each ml contains 0.01 gram of silver nitrate.

EQUATION

This means that 0.225 gram of silver nitrate has reacted. Now using this information we can then calculate the exact concentration of chloride in the sample.

Measuring and testing water,  
underwater shots, fish,  
mercury poisoning story,  
pollution, pulp and paper  
mill shots, chemist in lab

NARRATOR (MUSIC under):

But salinity measurements are only a small -- and relatively easy part of the effort to discover what effects the nation's waters. Other substances are present in only very minute quantities -- in some cases just a few parts per million. Take mercury for instance. In the 1960s, mercury residues were found in fish coming from the English Wabegone River in Canada. Several members of the local population were severely affected. Mercury poisoning can cause serious neurological damage, resulting in weakened muscles, loss of vision and loss of brain function. And it can cause death. Researchers discovered that certain bacteria in sediments at the bottom of rivers and lakes convert metallic mercury into a slightly soluble, and thus highly dangerous compound called methylmercury. The source of the mercury in the Canadian waters could have been the nearby pulp and paper mill. Some industrial plants had been dumping as much as 100 kilograms of mercury every day. In response, officials in Canada and the United States began to prohibit discharge of mercury from industrial plants. (cont.)

NARRATOR cont:

The Food and Drug Administration now allows only one-half of one part per million of mercury. This means that only one-half of a milligram of mercury can be present per kilogram of water. How do chemists measure such small amounts?

DS in lab

DON SHOWALTER (SYNC):

To find the concentration of a small amount of a dissolved substance such as mercury we use a method called spectrophotometry. Now this is a spectrophotometer. It measures the amount of light that a substance absorbs. The measure that it gives us is called absorbance. Let's see how it works. Remember when we were weighing the tablet, how we used that standard gram to make sure that the balance was accurate. We should do the same thing when we make our mercury measurement using the spectrophotometer. Now this is a blank solution. It has no mercury in it. When we put it into the spectrophotometer it should measure zero absorbance. As it does. The next step involves something that we talked about in an earlier part of the program -- a standard solution. Now this is a standard solution of mercury. (cont.)



DON SHOWALTER cont:

We've put it into the spectrophotometer and this is the absorbance. Now let's look at that on a graph.

GRAPHIC: Graph

NARRATOR:

The line across the bottom represents the concentration of the pollutant in the solution. The line running up and down represents the reading from the spectrophotometer, called absorbance. First, one takes the known value of the concentration and matches it to the absorbance reading, as shown here, making a point where the two readings intersect.

DS in lab

DON SHOWALTER (SYNC):

Now this point isn't much use to us by itself. However, if we would accurately dilute our standard with a measured amount of water, something interesting begins to happen.

GRAPHIC: Calibration curve

NARRATOR:

As each new point is added, you can see that they start to form a pattern. If a line is drawn through the pattern made by these points, it looks like this. This line is called a calibration curve.

DS in lab

DON SHOWALTER (SYNC):

Now we are ready to find the unknown concentration of the mercury in the sample. But first, we need to get its reading from the spectrophotometer.

GRAPHIC: Absorbance  
graph

NARRATOR:

This reading from the spectrophotometer is put on the vertical line for absorbance. Starting from this absorbance value, we find the point where it meets the calibration curve. Then, a line is dropped from there to the concentration part of the graph. This gives us a number for the previously unknown amount of the pollutant.

DS in lab

DON SHOWALTER (SYNC):

Now, using the spectrophotometer and the calibration curve we have measured the concentration of mercury in the sample. Now everyday life the chemist would do this measurement at least three times. Why?

Chemists at work  
in labs

NARRATOR (MUSIC under):  
Measurements are performed at least three times in order to insure what scientists call a precise measurement. A measurement is precise if the measuring instrument and procedure yield values that are very close to each other every time the measurement is done.

DS in lab

DON SHOWALTER (SYNC):  
Let's see what accuracy and precision would look like if we made three different measurements of the concentration of mercury in our sample.

GRAPHIC: Precision  
and accuracy

NARRATOR:  
As each new measurement of the same sample is added to the graph, it becomes clear that not every measurement is exactly the same. This is what happens in most measurement situations. Look closely at the concentration line. If the measurements are grouped tightly together like this, the measurement is said to be precise. The tighter the cluster, the more precise the measurement. A scientist's goal is to make measurements that are both precise and accurate. (cont.)

NARRATOR cont:

If the measurements we have taken are clustered around what we have found to be the true value, then our measurement is both precise and accurate. The average of all the measurements is very close to the true value. It is possible for a measurement to be precise, but not accurate. You can see that these measurements are tightly grouped, but they are not close to the true value. They are not accurate. Compare this to a measurement that is both accurate and precise. It is even possible for a measurement to be accurate, but not precise, like these measurements. They are not tightly grouped. They are not precise. But because their average is very close to the true value, this measurement turns out to be accurate. Again, you can see how they compare to the measurement that is both precise and accurate.

Crest commercial

LITTLE GIRL (SYNC):

Oh Mom. Look Mom, no cavities.

MOTHER (SYNC):

Oh Debbie, really?

LITTLE GIRL (SYNC):

The dentist says no new cavities.

Drinking fountains,  
dentist's office

NARRATOR (MUSIC and NAT  
SOUND under):

Fluoride's first promotion. Today, in  
our toothpaste and water, we take  
fluoride for granted. But it took  
extremely accurate and precise  
measurements to discover how much  
fluoride was beneficial. Tom Reeves is  
the national fluoride engineer for the  
Public Health Service.

INTERVIEW: Tom Reeves,  
National Fluoride Engineer,  
Public Health Service

SUPER: Tom Reeves

TOM REEVES (SYNC):

Fluoridation has a very interesting and  
intriguing history and it started way  
back in the very early 1930s when a  
dentist went out to Colorado Springs,  
Colorado to start his practice and when  
he had a lot of the children come into his  
office he noticed that they had a brown  
stain and he called that a Colorado  
Brown Stain.

Archival photographs of  
children and chemist in lab,  
close up of Colorado Brown  
Stain, shot of Colorado River

NARRATOR (MUSIC under):  
The dentist, Dr. Charles McKay,  
discovered something fascinating about  
the children with Colorado Brown Stain.  
Although their teeth were discolored,  
they had almost no cavities. McKay  
suspected that something in the local  
water supply was responsible. It was  
fluoride, but in very minute amounts.

INTERVIEW: Tom  
Reeves cont.

TOM REEVES (SYNC):  
When they had finally determined that  
fluoride chemicals was the material that  
was causing the brown staining, they  
couldn't determine at what levels the  
problem existed -- for example was it  
one part per million, was it a hundred  
parts per million, was it a half a part per  
million. And part of this problem was  
they could not measure it at that low a  
level.

Archival photographs  
of chemists at work  
and children

NARRATOR (MUSIC under):

It took years to develop a technique that could accurately measure small concentrations of fluoride. Then more research was needed to discover the proper amount to prevent cavities. Finally, they identified it. One part of fluoride for every million parts of drinking water.

INTERVIEW: Tom  
Reeves cont.

TOM REEVES (SYNC):

Here you were that we had something in our very fingertips that we could inexpensively add or subtract to the drinking water and virtually wipe out or greatly reduce dental cavities was a really an outstanding thing.

Analyzing water, drinking  
fountain

NARRATOR (MUSIC under):

Today, the fluoride in your water is closely monitored. If the concentration is too high, the Colorado Brown Stain, or fluorosis could result. If the concentration is too low, you can get cavities.

INTERVIEW: Tom  
Reeves cont.

TOM REEVES (SYNC):  
I can't think of anything that more  
clearly shows the importance of  
measurement than the fluoride  
measurement. It's the key to solving the  
mystery in the 1930s and it's also the  
key to getting an accurate amount of  
chloride in the water today so that you  
get the full dental benefits. But you  
don't get the problem of fluorosis. So  
it's a very important measurement and  
it's literally changed the lives of millions  
of people around the world.

Crest commercial

ANNOUNCER (VO):  
You can cut your family's cavity rate  
almost in half. You too may hear,

LITTLE GIRL (SYNC):  
Oh Mom. Look Mom, no cavities.

SUPER: MEASUREMENT,  
THE FOUNDATION OF  
CHEMISTRY



MONTAGE: Chemists at work  
in labs, standard kilogram,  
analyzing water, lab  
demonstrations, beach and  
fishing shots

NARRATOR (MUSIC under):  
To review. Standards assure that  
measurements can be communicated and  
reproduced anywhere in the world. A  
kilogram is the same no matter where  
you are. In order to make chemical  
measurements a variety of techniques  
are being developed. Sometimes the  
amount of a substance can be measured  
directly on a balance. More often one  
substance is dissolved in another. It has  
to be measured indirectly using  
techniques like titration. Our health and  
our livelihoods depend on the chemistry  
of our environment and measurement is  
the foundation of our ability to  
understand that chemistry.

RH in lab

ROALD HOFFMANN (SYNC):  
I'm in an analytical laboratory.  
Someone has brought here a sample of  
some copper ore to be analyzed. Now  
that analysis has to be believed by  
everyone when it leaves this laboratory.  
The chemists here have devised an  
elaborate procedure for doing it. The  
analysis begins with a careful weighing  
of the sample of the ore. (cont.)

ROALD HOFFMANN cont:

Then in this hood it's digested with a very precise volume of perchloric acid. You know when I think about it what this is is very much like a cookbook recipe. And just in the same way that no one would buy a copy of the cookbook in which the recipes were not repeatable, no one is going to believe the analytical chemist unless the prescription he gives for the analysis is repeatable not just here but just as easily in Dar Es Salaam or Novosibirsk. What we have discussed in this program is how chemists determine what they have. The next logical question is to ask how did it happen. Why? These we will look at in the next program.

Credits, Closing Montage, Closing Music

Copyright © 1988  
Educational Film Center  
and The  
University of Maryland

The World of Chemistry Logo.

A Production of  
UNIVERSITY OF MARYLAND  
AND  
EDUCATIONAL FILM CENTER

The Annenberg/CPB Project Logo

Funder Credits

1-800-LEARNER

PBS Logo